CONFIDENTIAL

Copy 315
RM L55L15a

NACA

CASE FILE COPY

RESEARCH MEMORANDUM

SOME EFFECTS OF AIRCRAFT CONFIGURATION ON STATIC
LONGITUDINAL AND DIRECTIONAL STABILITY
CHARACTERISTICS AT SUPERSONIC
MACH NUMBERS BELOW 3

By M. Leroy Spearman and Arthur Henderson, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

CLASSIFICATION CHANGED TO UNCLASSIFIED
AUTHORITY: NASA PUBLICATION ANNOUNCEMENT NO. 4
EFFECTIVE DATE: FEBRUARY 10, 1959
WHL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

February 17, 1956

CONFIDENTIAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

SOME EFFECTS OF AIRCRAFT CONFIGURATION ON STATIC LONGITUDINAL AND DIRECTIONAL STABILITY CHARACTERISTICS AT SUPERSONIC MACH NUMBERS BELOW 3

By M. Leroy Spearman and Arthur Henderson, Jr.

SUMMARY

The longitudinal problem of airplane configurations at supersonic Mach numbers below 3 is generally one of excessive stability so that the large control deflections required for trim may result in undesirably low trimmed lift-drag ratios. These characteristics may be relieved to a certain extent by positive increases in the pitching moment at constant lift that may be effected through the use of such devices as body camber.

The directional stability is characterized by a rapid deterioration with increasing Mach number. This trend results primarily from the loss in vertical-tail lift-curve slope with increasing Mach number and is considerably aggravated for most configurations by the highly unstable wing-body combinations that occur from the use of large high-fineness-ratio bodies and from the far rearward center-of-gravity positions. Hence, a large percentage of the tail contribution is lost in overcoming the unstable moment of the wing-body combination and only a small percentage is available to provide a positive stability margin. Any decrease in tail contribution resulting from interference effects, aeroelasticity, control deflection, and so on, subtracts directly from the stability margin and may lead quickly to directional divergence. The concept of the wing-body induced sidewash field has been shown to be of some importance in qualitatively determining the effect of angle of attack on the directional characteristics of the wing-body combination and on the tail contribution.

INTRODUCTION

Aircraft designed for flight in the supersonic Mach number range up to about 3, frequently encounter some problems of static stability and control. These problems are apparent in the case of longitudinal stability as an excessive static margin that results in the need for large

control deflections to trim and, as a consequence, high trim drags and low trim lift-drag ratios may occur.

The directional problem, on the other hand, is primarily one of insufficient stability. The magnitude of directional stability decreases quite rapidly with increasing Mach number and as a result the directional characteristics become particularly sensitive to angle of attack changes, to aeroelasticity, and to various configuration changes such as the addition of external stores.

It is the purpose of this paper to describe some of the sources of these problems and to indicate some means by which these problems might be alleviated.

SYMBOLS

C_D drag coefficient

C_L lift coefficient

C_m pitching-moment coefficient

C_n yawing-moment coefficient

C_{n_β} yawing moment due to sideslip

C_Y lateral-force coefficient

C_{Y_β} lateral force due to sideslip

ΔC_{Y_t} increment in lateral-force coefficient contributed by vertical tail

D drag

i_t incidence of horizontal tail

L lift

M free-stream Mach number

V free-stream velocity

v_σ lateral velocity component due to sidewash

α angle of attack

β angle of sideslip

DISCUSSION

Longitudinal Stability

The longitudinal problem, which will be considered first, is primarily one of excessive stability. This excessive stability is a result of several generally well-known factors. These factors include the increase in stability of the wing-body combination that is caused by a rearward shift of the wing center of pressure and a stabilizing interference effect of the wing lift carried over to the afterbody. The stability is further increased because of the loss of the subsonic type of wing downwash at the tail since the major portion of this downwash is confined to the wing-tip Mach cones and at supersonic speeds begins to move off of the horizontal tail. In addition, in the case of most low-tail airplanes, stabilizing upwash from the body may be encountered. At the same time that the stability is increased, the effectiveness of the tail in producing pitching moment is reduced. As indicated by the example shown in figure 1, these effects combine to cause large untrimmed pitching moments that must be overcome through rather large control deflections, and the result is high trim drag and low trim lift-drag ratios. In addition, because of the large control deflections required for trimming, little excess control deflection may be available for maneuvering.

Some recent investigations have indicated that body camber, similar to that proposed from area-rule considerations, may be useful in providing positive increments of pitching moment at constant lift in such a manner as to relieve the control-deflection requirements. The effects of body camber are shown in figure 2 for a 60° delta wing-body at $M = 1.6$. The reflexed or cambered body produces constant pitching-moment increments throughout the lift range with no change in drag and should be useful in shifting the pitching-moment level for a basic configuration so that the pitch-control requirements might be relieved and the drag due to trimming reduced.

Although the excessive longitudinal stability presents serious control problems in the Mach number range from 1 to about 2, there are indications that a reduction in longitudinal stability will occur as the Mach number increases toward 3 or above. Such an effect is indicated in figure 3 for three different aircraft configurations in the Mach number range from about 1.4 to 3.0. Here there is a general decrease in longitudinal stability for the complete configuration that is apparently

dictated by a decrease in the stability of the tail-off configuration. This stability decrease occurs in part from a decrease in the stabilizing carryover lift effect of the wing on the afterbody as indicated in reference 1. At higher Mach numbers, the added effects of large changes in dynamic pressure in the wing flow field may cause additional changes in the longitudinal stability.

Directional Stability

The second phase of the supersonic stability problem which will now be discussed is that of static directional stability in the supersonic Mach number range below 3. The directional stability, in contrast to the longitudinal problem, is characterized by a rapid deterioration in the stability with increasing Mach number. A typical variation of the stability parameters C_{n_β} and C_{Y_β} with Mach number is shown in figure 4. It will be noted that there is a progressive decrease in the stability level of the complete configuration until a Mach number is reached where directional instability occurs. This loss in stability results from the characteristic decrease in lift-curve slope of the vertical tail with increasing Mach number, which is reflected, in turn, in a decreased tail contribution to the total stability.

The situation is considerably aggravated for most current designs by a large unstable wing-body yawing moment. This large unstable moment generally results from the use of large, high-fineness-ratio fuselages with far rearward center-of-gravity positions. The adverse effects of such center-of-gravity positions on directional stability are twofold in that the unstable yawing moment of the body is increased while the vertical-tail moment arm is reduced.

The results shown are for zero angle of attack and for a rigid model. It will be noted that a considerable portion of the tail contribution is required to overcome the large unstable wing-body yawing moment. It is obvious that any loss in vertical-tail contribution resulting from wing-body wakes, interference flow fields, or vorticity – as well as aeroelastic effects – could readily lead to directional instability. The problem is most acute at the higher Mach numbers where the stability level is already marginal.

A means by which the tail contribution to C_{n_β} can be increased by a relatively simple modification is illustrated in figure 5. These results are for zero angle of attack and a Mach number of 2.6. The results for the basic tail indicate a reversal in C_{n_β}. The modification, which consisted of the addition of wedges to both sides of the trailing-edge portion of the vertical tail, removed the reversal and resulted in a substantial

increase in tail effectiveness. This improvement was obtained with only a slight increase in drag. As shown by the results on the right-hand side of figure 5, the effectiveness of the wedges, as predicted by two-dimensional shock-expansion theory, is in good agreement with the experimental results.

The results thus far have been confined to zero angle of attack. An example of the angle-of-attack effects that might occur are shown in figure 6 for a 35° swept-wing airplane at $M = 1.6$. The directional stability decreases quite rapidly with angle of attack and instability occurs above about 10°. The nonlinear variation of C_n with β that is apparently influenced by the wing-body characteristics may add considerably to the directional problems since regions of instability might be reached through rudder deflections, for example.

In such cases, the directional instability may be delayed to higher angles of attack or higher Mach numbers simply by increasing the size of the vertical tail. Indiscriminate use of this method, of course, may result in undesirably high lateral forces and rolling moments and may increase the structural and weight problems associated with the vertical tail.

The loss in directional stability indicated here with increasing angle of attack and for other configurations in this Mach number range appears to be due in part to an effect of the disturbance caused by the wing-body juncture acting on the vertical tail and afterbody. This wing-body disturbance is apparent in the schlieren photographs shown in figure 7 for a high-wing position and a low-wing position of a 45° swept wing on a body of revolution at angles of attack of 5° and 10° and at a Mach number of 2. The shock lines from the wing are visible in both cases. The disturbance induced by the wing-body juncture is clearly visible for the high-wing case and is alined in the free-stream direction so that it passes the region normally occupied by the vertical tail. For the low-wing arrangement, the disturbance is confined to the afterbody region and hence is not visible in the photographs.

This wing-body disturbance is the same as that which occurs at subsonic speeds, and at angles of sideslip provides the same type of sidewash distribution at the vertical tail as that discussed in reference 2. At Mach numbers somewhat greater than 2, however, where the Mach lines from the wing are directed more nearly over the vertical tail, additional changes in tail contribution, as pointed out in reference 2, might be experienced because of the large changes in dynamic pressure in the wing flow field.

Some effects of the wing-body induced sidewash field are shown in figure 8 for a wing-body-tail combination at a Mach number of 2. The nature of the induced sidewash for the high- and low-wing positions is

shown in the upper-right diagram. This sidewash results from the differential wing pressures near the wing root that are created by the lateral component of velocity due to sideslip. For the high-wing case, this sidewash is adverse above the center of the wing wake and is favorable below it. The reverse is true for the low-wing case. At zero angle of attack, the afterbody lies in the same type of flow region for either wing position and the values of C_{n_β} are the same for the tail-off configurations. With increasing angle of attack, the low-wing arrangement becomes increasingly unstable since the afterbody moves down through a region of adverse sidewash. For the high-wing arrangement, there is little change in stability with increasing angle of attack since the afterbody moves into an undisturbed flow region.

With the addition of the vertical tail at $\alpha = 0^\circ$, both configurations become stable. However, the tail contribution is less with the high wing since this arrangement places the tail in a region of adverse sidewash. With increasing angle of attack, the tail contribution continues to decrease for the high-wing arrangement as the tail passes through the region of adverse sidewash. For the low-wing arrangement, the tail contribution increases with increasing angle of attack as the tail passes through a region of favorable sidewash.

The effect of the wing sidewash on the vertical-tail loading, as obtained from pressure measurements on the tail, is shown in the lower right-hand side of figure 8. At $\alpha = 0^\circ$, the overall loading is less for the high-wing position, and, at $\alpha = 15^\circ$, the loading actually changes sign near the root of the vertical tail for the high-wing position. Unfortunately, in either case, the directional stability for the complete configurations reduces with increasing angle of attack but for two different reasons – for the high wing, because of a decreasing tail contribution, and, for the low wing, because of an increase in the instability of the wing-body combination. These effects of wing-body induced sidewash are dependent on the wing position relative to the body crossflow. The body crossflow, in turn, is dependent on the body cross-sectional size and shape.

Some effects of various tail modifications on the directional stability of two different configurations at Mach numbers of 1.6 and 2 are shown in figure 9. Both configurations have body shapes and wing positions that might be expected to cause adverse sidewash in the wake above the wing-body juncture. As a result, the variation of C_{n_β} with angle of attack indicates a large loss in vertical-tail contribution for the basic tails whereas the tail-off configurations show some improvement. For the configuration shown on the left-hand side of figure 9, the addition of a dorsal fin had little effect on C_{n_β} since the fin was placed in a region of adverse sidewash. The addition of a small ventral fin

having about two-thirds the area of the dorsal fin provided a stabilizing increment of C_{n_β} that increased slightly with angle of attack because of the more favorable flow beneath the body.

For the configuration shown on the right-hand side of figure 9, modifications to the basic tail consisting of an extended chord and of an extended tip were made. These modifications provided equal increments of C_{n_β} at zero angle of attack. With increasing angle of attack, however, the increment provided by the extended chord decreases since this area extension is adversely affected by the sidewash. The increment of C_{n_β} provided by the extended tip remains essentially constant with angle of attack up to 15° since this area extension remains above the flow-field disturbance from the wing-body juncture.

The configuration shown in figure 10 has a midwing with a large negative dihedral angle. This arrangement places the wing in a position relative to the body crossflow such that a favorable sidewash above the wing similar to that for a low-wing circular-body configuration might be expected. Accordingly, the variation of C_{n_β} with angle of attack indicates little change in the tail contribution, although the directional stability decreases as a result of the increasing instability of the tail-off configuration. The substitution of an enlarged tail in the region of favorable sidewash causes a large increase in C_{n_β} at $\alpha = 0^{\circ}$ and an increase in the tail contribution with increasing angle of attack. The addition of a ventral fin to the basic model is beneficial, but its effect is much less than that for the enlarged tail, although the area of the ventral fin is about twice that of the area increase for the enlarged tail. It might be expected that, for a configuration of this type, a chordwise extension to the vertical tail would be more effective than a spanwise extension in increasing C_{n_β}.

It should be pointed out that ventral fins or lower-surface vertical tails should always provide good directional characteristics at high angles of attack since these surfaces, regardless of the initial wing-body induced sidewash characteristics, move into a region of undisturbed flow. The directional characteristics of a lower-surface vertical-tail arrangement and an upper-surface vertical-tail arrangement at a Mach number of 2 are compared in figure 11. The directional stability decreases rapidly with angle of attack for the conventional tail arrangement, primarily because of a decrease in the tail contribution. For the lower-surface arrangement, however, a large increase in the directional stability with angle of attack for the complete model is indicated in spite of a decrease experienced by the tail-off configuration.

An additional example of the sensitivity of the directional stability to configuration changes is shown in figure 12. This figure shows some

effects of two different external-store installations on a 45° swept-wing airplane at an angle of attack of 15° and $M = 1.4$. Both installations – one body-mounted store and two wing stores – caused an increase in the lateral force. The body-store configuration was directionally unstable whereas the two wing stores caused a fairly large increase in the directional stability. These changes in C_{n_β} were somewhat greater than would be expected from consideration of the isolated store forces and indicate rather large mutual interference effects between the various components that tend to complicate the quantitative prediction of the store effects.

CONCLUDING REMARKS

The longitudinal problem of airplane configurations at supersonic Mach numbers below 3 is generally one of excessive stability so that the large control deflections required for trim may result in undesirably low trimmed lift-drag ratios. These characteristics may be relieved to a certain extent by positive increases in the pitching moment at constant lift that may be effected through the use of such devices as body camber.

The directional stability is characterized by a rapid deterioration with increasing Mach number. This trend results primarily from the loss in vertical-tail lift-curve slope with increasing Mach number and is considerably aggravated for most configurations by the highly unstable wing-body combinations that occur from the use of large high-fineness-ratio bodies and from the far rearward center-of-gravity positions. Hence, a large percentage of the tail contribution is lost in overcoming the unstable moment of the wing-body combination and only a small percentage is available to provide a positive stability margin. Any decrease in tail contribution resulting from interference effects, aeroelasticity, control deflection, and so on, subtracts directly from the stability margin and may lead quickly to directional divergence. The concept of the wing-body induced sidewash field has been shown to be of some importance in qualitatively determining the effects of angle of attack on the directional characteristics of the wing-body combination and on the tail contribution.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 2, 1955.

REFERENCES

1. Love, Eugene S.: Supersonic Wave Interference Affecting Stability. NACA RM L55L14a, 1956.

2. Malvestuto, Frank S., Jr., and Alford, William J., Jr.: Effects of Wing-Body Geometry on the Lateral Flow Angularities at Subsonic Speeds. NACA RM L55L26a, 1956.

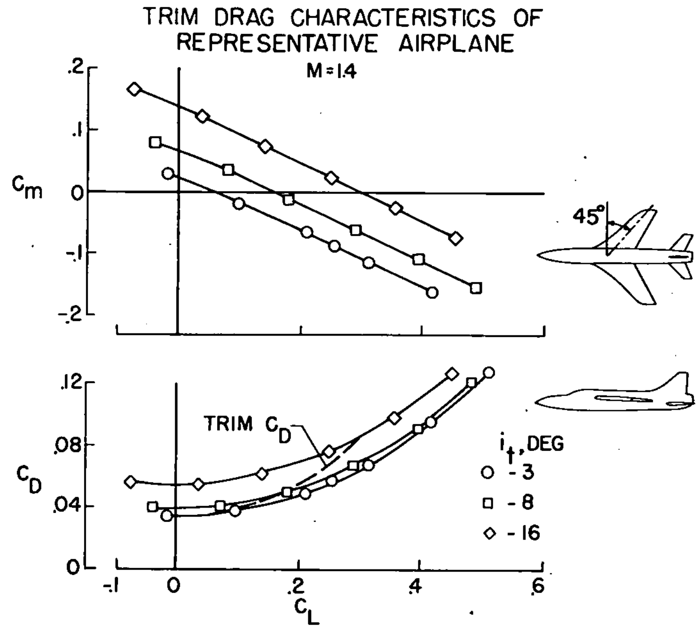


Figure 1

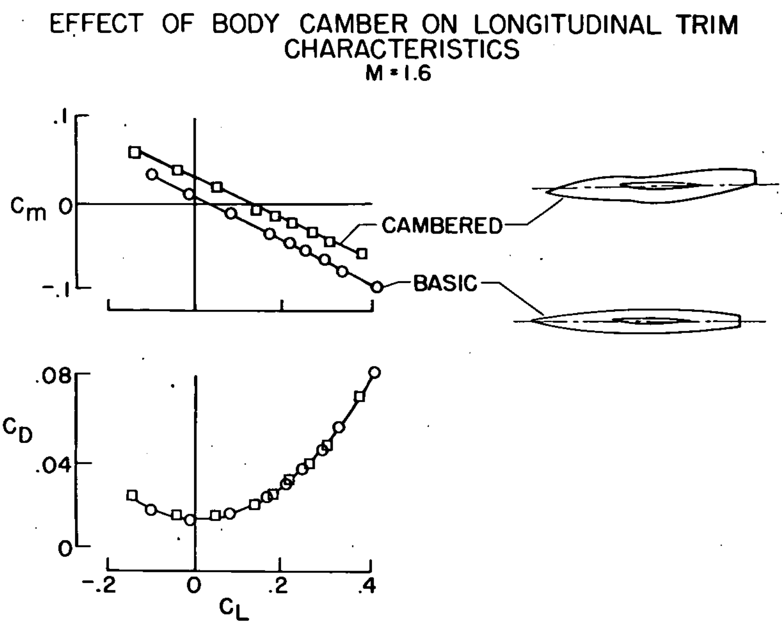


Figure 2

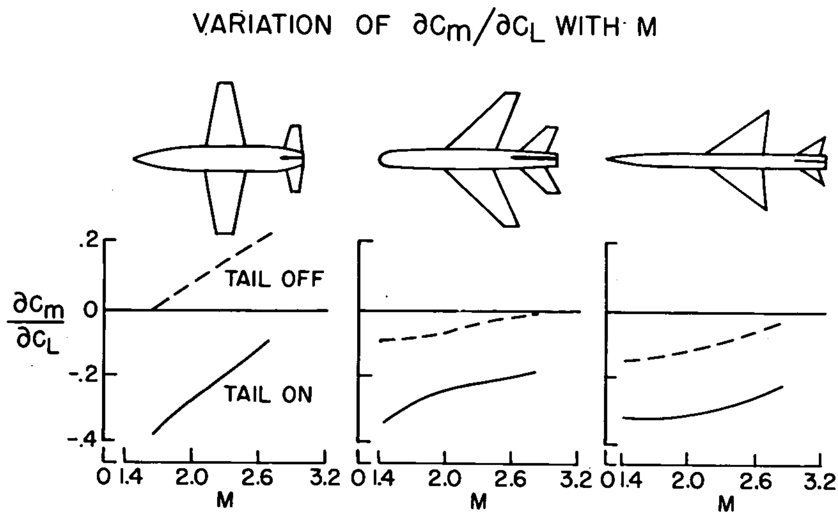


Figure 3

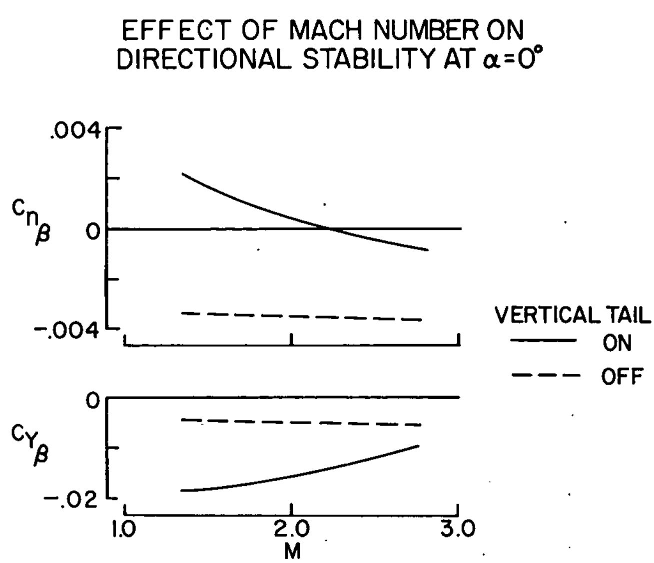


Figure 4

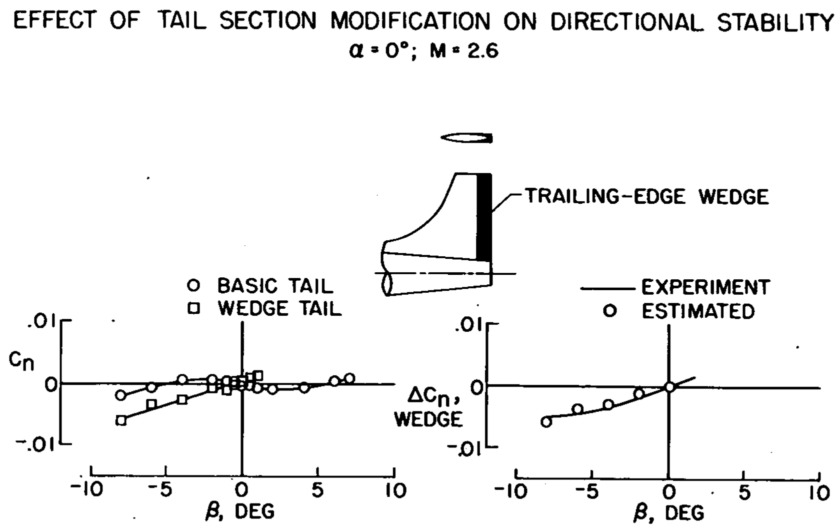


Figure 5

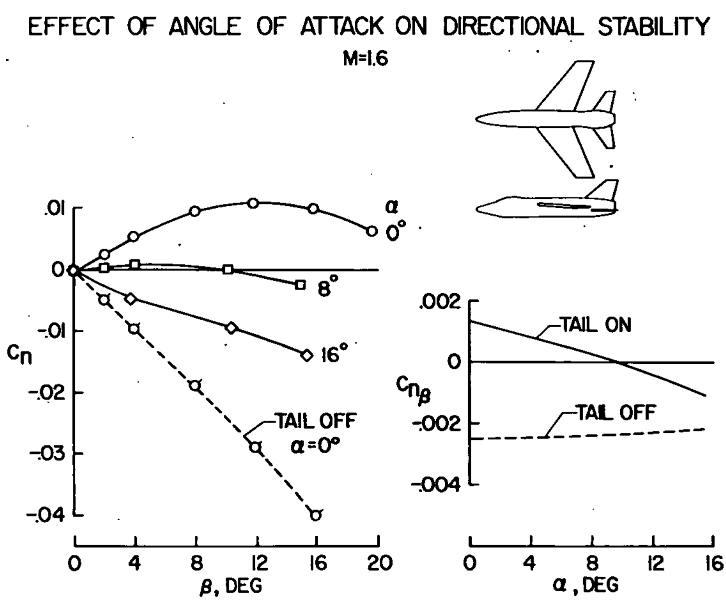
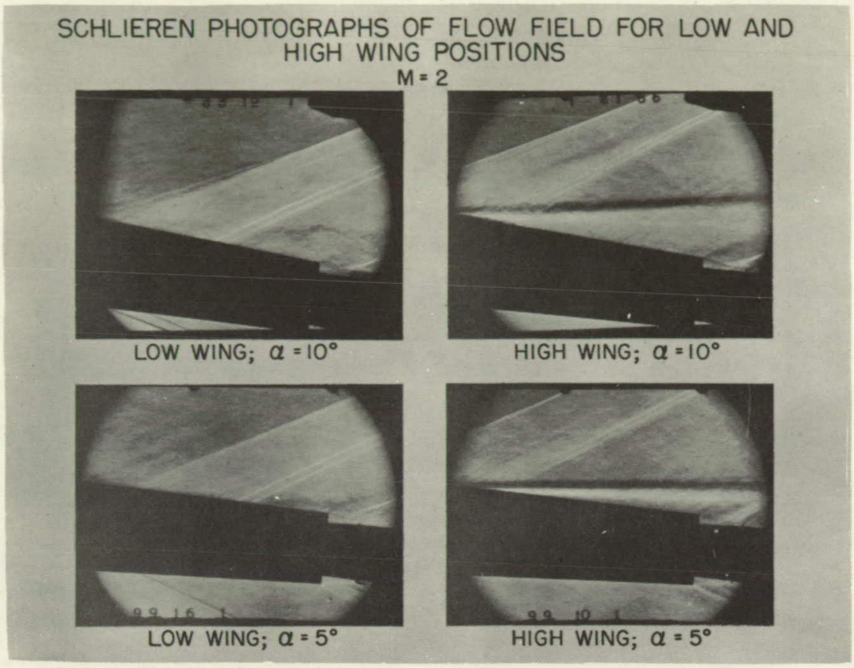


Figure 6



L-91760

Figure 7

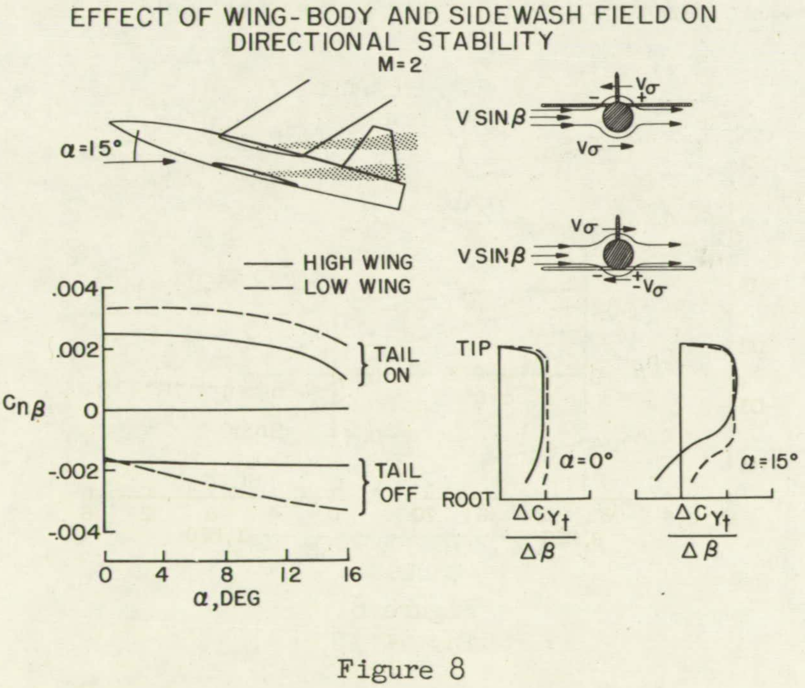


Figure 8

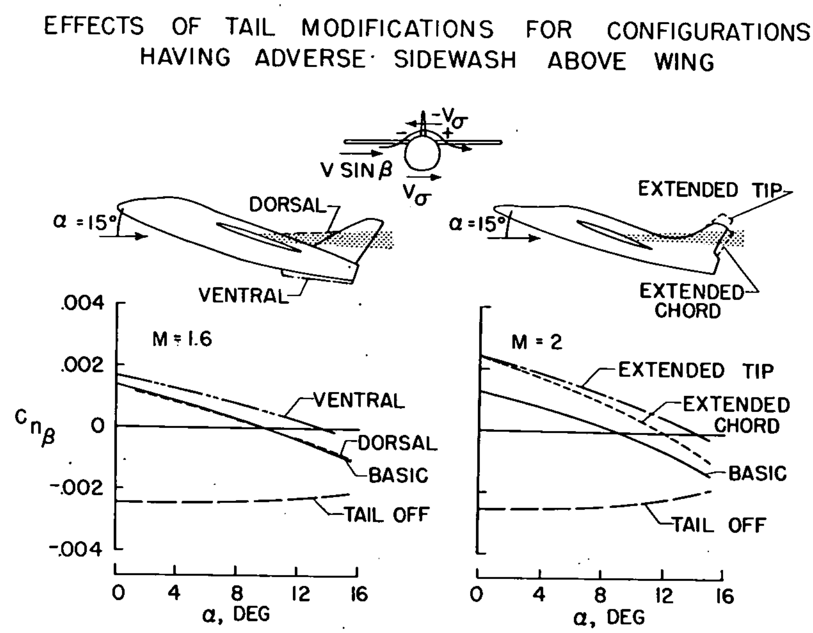


Figure 9

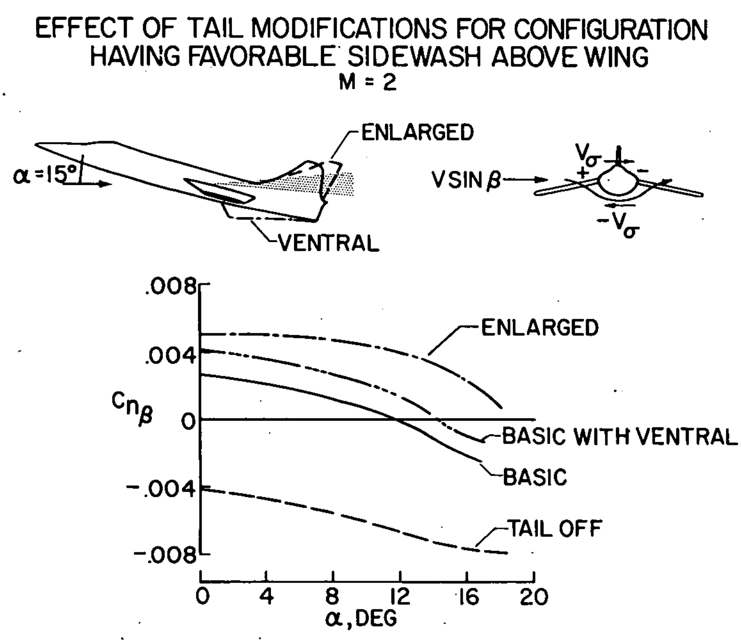


Figure 10

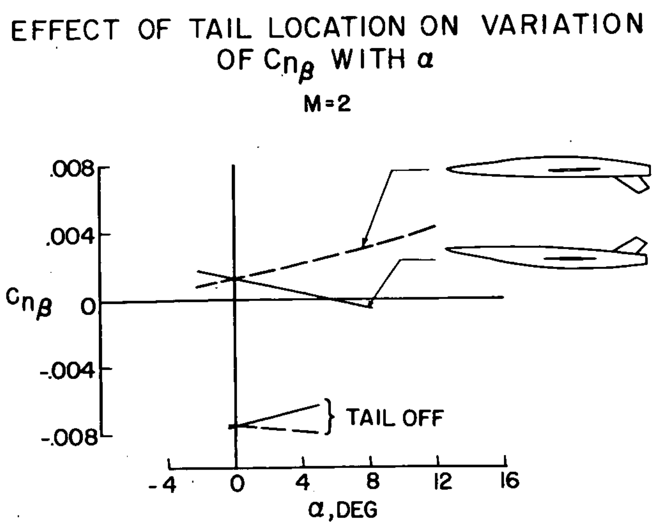


Figure 11

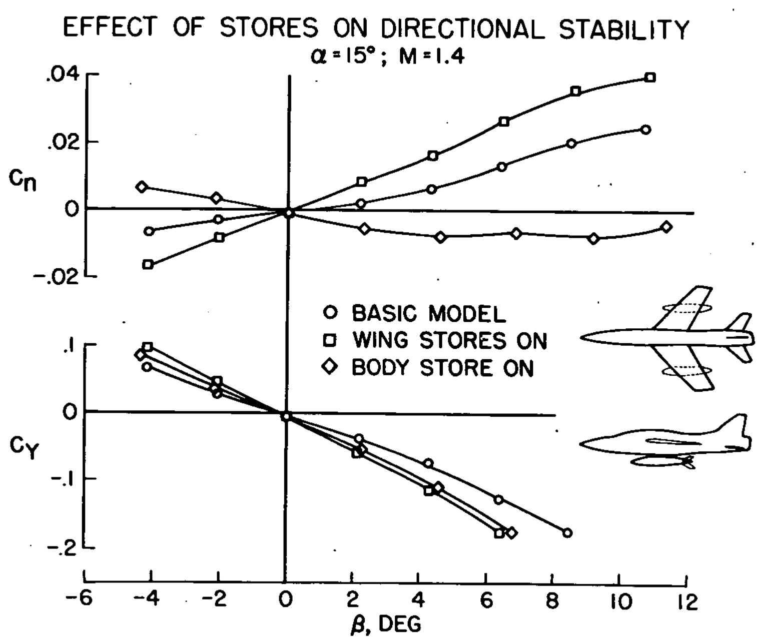


Figure 12

NACA - Langley Field, Va.